TABLE 2.—*Solar radiation intensities at Madison, Wis., 1913 to 1915, inclusive*—Concluded.

[Gram-calories per minute per square centimeter of normal surface.]

Date.	Sun's zenith distance.										
	0.0°	43.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°
	Air mass.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
A. M. 1915.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.
Dec. 2								1.08			
14				1.37							
28				1.46	1.39	1.32	1.25			0.99	
Means (1910-1915)				1.25	1.17	1.11	1.15	1.04	0.85	0.68	
P. M. 1912.											
Dec. 21					0.83	0.76	0.70				
22					0.83	0.76					
28					1.01						
1913.											
Dec. 11							1.01				
1914.											
Dec. 11					1.21	1.16					
19						1.12					
30						1.31					
1915.											
Dec. 13					1.29						
28					1.40	1.32	1.25				
Means (1910-1915)					1.29	1.10	0.33				

DURATION OF TWILIGHT.[1]

By twilight we mean the light experienced after sunset and before sunrise, and due to the reflection, diffraction, or diffusion of sunlight by the gas molecules, the water particles, and the dust of the atmosphere. The greater the distance of the sun below the horizon the higher and less dense are the atmospheric layers from which the light is received at the shaded surface of the earth. Observation has shown that under the most favorable atmospheric conditions the last trace of twilight disappears when the sun is from 16° to 18° below the horizon, indicating that above a height of 40 to 50 miles, or 60 to 80 kilometers, the air is too rare to reflect or diffuse an appreciable amount of sunlight.

The duration of twilight may be computed from the equation:

$$\cos h = \frac{\sin a - \sin \phi \sin \delta}{\cos \phi \cos \delta},$$

where a is the sun's altitude, considered minus below the horizon, δ is the solar declination or distance from the celestial equator, ϕ is the latitude of the place of observation, and h is the sun's hour angle from the meridian.

From the above equation it will be found that at the equator, at the time of the equinoxes, when the apparent path of the sun is along the prime vertical, it takes the sun 1 hour and 12 minutes to pass from the horizon to a point 18° below it, or vice versa. At the solstices, when the sun appears to describe a small circle about the earth's axis 23½° from the prime vertical, the time is 1 hour and 19 minutes. At latitude 49°, or the latitude of the northern boundary of the United States, where the sun's

apparent path is inclined 49° to the plane of the prime vertical, at the equinoxes it takes 1 hour and 52 minutes for the sun to pass from the horizon to a point 18° below. At the time of the winter solstice it takes 2 hours and 3 minutes, while at the time of the summer solstice the sun does not reach 18° below the horizon. In fact, there is a period of 22 days, from June 10 to July 2, inclusive, during which on the clearest nights the twilight may continue from sunset to sunrise.

Soon after sunset on very clear evenings there frequently appears in the western sky a rosy or purple glow, in the form of an arc about 20° to 25° in diameter with the sun at its center. It disappears when the sun is about 6° below the horizon, indicating that it comes from atmospheric layers not more than 5 or 6 miles (8 to 10 kilometers) above the surface of the earth. It is in these layers that convective action principally occurs, and they are therefore the dusty layers, as well as the layers that contain most of the atmospheric moisture. The purple glow is attributed to the diffraction of light by the dust and water particles in these layers. During the day the same process produces the whitish glow that is seen about the sun in clear weather.

With the disappearance of this glow the intensity of twilight becomes insufficient for the continuance of outdoor occupations. Hence it is the duration of this portion of the twilight, which Europeans term *civil twilight*, that is of practical interest and especially to those engaged in pursuits having to do with transportation, or any other line of out-door work that requires artificial lighting after nightfall, either for illumination or for signal purposes.

The intensity of twilight is not entirely dependent upon the position of the sun, however. The state of the sky is a modifying factor. Clouds on the western horizon, or a hazy condition of the atmosphere that may be due to either dust or moisture, noticeably diminish the twilight intensity, and in the case of very dense clouds may almost completely obliterate it. It is believed, however, that Table 1, which gives the duration of civil twilight or the time required for the sun to pass from the horizon to a point 6° below or vice versa, will be found useful to Weather Bureau officials and others. But it must be understood that the duration as given applies to clear sky conditions only and is too long for cloudy or hazy conditions. Furthermore, high mountains and buildings, or any objects that obstruct the horizon near where the sun rises or sets, will diminish the duration of twilight. It will be noted that at the Equator civil twilight only varies in duration from 24 minutes at the equinoxes to 26 minutes at the solstices, while at latitude 48°, near the northern boundary of the United States, it varies in duration from 36 minutes at the equinoxes to 43 minutes at the winter solstice and 48 minutes at the summer solstice. At Cleveland the variation is from 32 minutes at the equinoxes to 37 minutes at the winter solstice and 39 minutes at the summer solstice.

Table 1 gives the difference between the time when the center of the sun reaches the true horizon and the time it reaches a point 6° below, or vice versa. Without material error, we may add this interval to the time of sunset given in the Weather Bureau Sunshine Tables, or subtract it from the time of sunrise, to obtain the time of ending of civil twilight in the evening or its beginning in the morning. The time thus determined will be that at which the upper limb of the sun is 6° lower than it was at the time it appeared to rise or set on a true horizon, assuming normal atmospheric refraction, and mean solar diameter.

[1] *Reprinted from the paper* "Daylight illumination and the intensity and duration of twilight," by H. H. Kimball, Ph. D., presented to the Pittsburgh Section of the Illuminating Engineering Society, Cleveland, Ohio, Feb. 18, 1916, and printed by the society in its Transactions.

TABLE 1.—*Duration of civil twilight.*

[Time required for the sun to pass from the horizon to a point 6° below or vice versa.]

North latitude.	0°	10°	20°	25°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°
Date.							Minutes of time.								
Jan. 1	26	26	28	29	31	31	32	33	34	35	37	38	40	42	45
11	26	26	28	29	30	31	32	33	34	35	36	38	39	41	44
21	26	26	27	28	30	30	31	32	33	34	35	37	38	40	43
Feb. 1	25	25	27	28	29	30	31	31	32	33	34	36	37	39	41
11	25	25	26	27	29	30	30	31	32	33	34	35	36	38	39
21	24	25	26	27	28	29	29	30	31	32	33	34	35	37	38
Mar. 1	24	25	26	27	28	28	29	30	31	32	33	34	35	35	38
11	24	24	26	27	28	28	29	30	30	31	32	34	35	36	37
21	24	24	26	27	28	28	29	30	30	31	32	33	35	36	38
Apr. 1	24	24	26	27	28	29	29	30	31	32	33	34	35	37	38
11	24	25	26	27	28	29	30	30	31	32	33	34	36	37	39
21	25	25	26	27	29	29	30	31	32	33	34	35	37	39	41
May 1	25	25	27	28	29	30	31	32	33	34	35	37	38	40	43
11	25	26	27	28	30	31	32	33	34	35	36	38	40	42	45
21	26	26	28	29	31	32	32	34	35	36	38	40	41	44	47
June 1	26	26	28	29	31	32	33	34	36	37	39	41	43	46	49
11	26	27	28	30	32	32	34	35	36	38	39	42	44	47	51
21	26	27	29	30	32	33	34	35	36	38	39	42	44	48	51
July 1	26	27	28	30	32	32	34	35	36	38	39	42	44	47	51
11	26	26	28	29	31	32	33	34	36	37	39	41	43	46	49
21	26	26	28	29	31	32	33	34	35	36	38	40	41	44	47
Aug. 1	25	26	27	28	30	31	32	33	34	35	36	38	40	42	45
11	25	25	27	28	29	30	31	32	33	34	35	37	38	40	42
21	25	25	26	27	29	29	30	31	32	33	34	35	37	39	41
Sept. 1	24	25	26	27	28	29	30	30	31	32	33	34	36	37	39
11	24	24	26	27	28	29	29	30	31	32	32	34	35	36	38
21	24	24	26	27	28	28	29	30	31	31	32	33	35	36	38
Oct. 1	24	24	26	27	28	28	29	30	30	31	32	34	35	36	37
11	24	25	26	27	28	28	29	30	31	32	33	34	35	36	38
21	24	25	26	27	28	29	29	30	31	32	33	34	35	37	38
Nov. 1	25	25	26	27	29	29	30	31	32	33	34	35	36	38	40
11	25	26	27	28	29	30	31	32	32	34	35	36	37	39	41
21	26	26	27	28	30	30	31	32	33	34	35	37	38	40	43
Dec. 1	26	26	28	29	30	31	32	33	34	35	36	38	40	41	44
11	26	26	28	29	31	31	32	33	34	35	37	38	40	42	45
21	26	27	28	29	31	31	33	33	34	36	37	39	40	43	45

In Table 2 are given photometric measurements of the intensity of twilight with the sun at different distances from the horizon, made by Mr. A. H. Thiessen at Salt Lake City, Utah. They are in accord with Mount Weather observations published in this REVIEW, December 1914, 42:652, and show that on clear days with the sun 6° below the horizon the twilight is less than 1 per cent as intense as it is immediately after sunset; or, the illumination is approximately that produced by a standard candle at a distance of 3 feet, namely, 0.1 foot-candle, as compared with 10,000 foot-candles at noon on a bright summer day. And yet, on November 6, 1913, I was able to read a graduated circle to tenths of degrees until the sun was nearly 7° below the horizon, by holding the instrument normal to the bright western sky.

TABLE 2.—*Photometric measurements of daylight and twilight illumination at Salt Lake City, Utah, on a surface normal alternately to the zenith and the western horizon Dec. 15, 1914.*[1]

	Sun's—		Illumination.
	Hour angle.	Altitude.	
	H. m.	*°*	*Foot-candles*
Time of observed sunset	4 19	+2.8	
	4 22	+1.6	[2] 206
	4 25	+1.1	[3] 87
Computed time center of sun's disk was on true horizon, disregarding atmospheric refraction	4 37	±0.0	
	4 41	−0.6	[2] 42
	4 44	−1.1	[3] 20
	5 01	−4.0	[2] 1.6
	5 06	−4.8	[3] 0.4
	5 12	−5.2	[2] 0.12
	5 14	−6.2	[3] 0.07

[1] Dec. 15, 1914. Sunset clear behind Oquirrh Mountains, which are about 2,000 feet above the valley.
[2] Photometric surface normal to western horizon.
[3] Photometric surface normal to zenith.

A LUNAR HALO OF JULY 24, 1861.

Mr. William B. Frew, now 87 years of age and for many years our cooperative observer at Aledo, Ill., sends the accompanying old sketch, by himself, of an interesting case of lunar halos and paraselenæ which he observed in Mercer County, Ill., on July 24, 1861. He states:

The moon seemed to be giving full light. The circles were plainly marked and the "mocks" had about half the brilliancy of the moon. The paraselenæ were very bright, specially within the interior ring. The cross of light near the moon had about half the light of the moon and gradually decreased toward the circumference of the circle. The lower circle was too near the horizon to present another intersection below.

At about 11 o'clock the next day [July 25, 1861] parhelia of precisely the same form, though not quite so brilliant, were observed. I recollect the whole scene as one of the most beautiful I ever saw in that line.
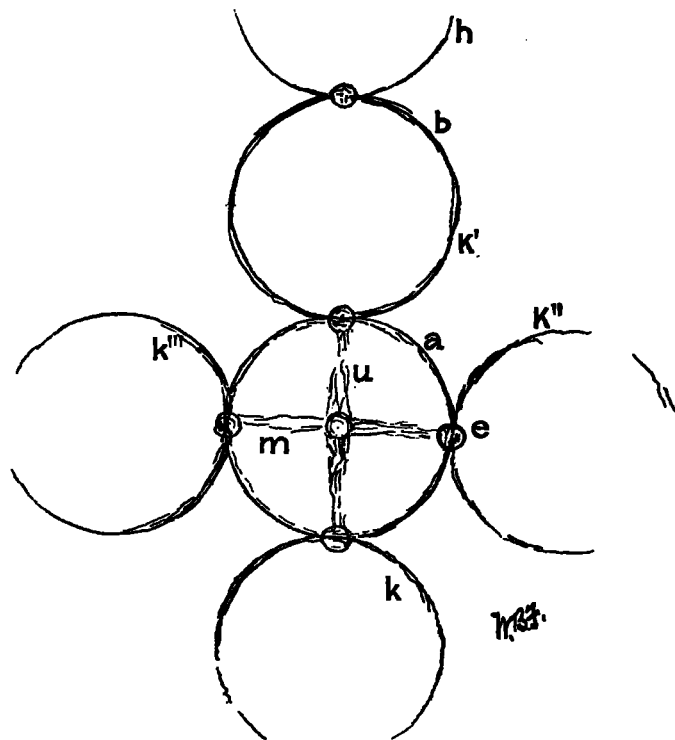

FIG. 1.—Lunar halos observed and sketched in Mercer County, Ill., July 24, 1861 (W. B. Frew).

Mr. Frew's old sketch is faithfully reproduced here in figure 1, just as he furnished it. To the writer it seems probable that the four fragmental curves *k-k'''* were actually the extraordinary tangential arcs to the 22°-halo, and that the curve *k'* of this group was not actually continuous through the arc *b* as here represented. On this interpretation, the arc *h* was probably the circumzenithal arc and *b* with its bright spot was the arc and vertical paraselena of 46°. Perhaps the detached fragment of an arc indicated to the right of *k''* was also part of the 46°-halo.

The lunar cross *mu* is of course composed of a part of the paraselenic circle, *m*, and a lunar pillar, *u*, of Bravais' "second class."

Unfortunately, the absence of all instrumental measurements greatly detracts from the value of the record.

Somewhat similar lunar halos and crosses observed in North Dakota and in Pennsylvania during February, 1894, will be found described in this REVIEW, February, 1894, 22:76.—C. A., jr.